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Analysis of the Effects of Palm Kernel Shells and Seeds on the Microstructure and Mechanical Behavior of Cast Aluminum Pulley Made with Green Sand Mold

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Abstract

This study examines the effects of palm kernel shells (PKS) and palm kernel seeds as reinforcing additives on the microstructure and mechanical properties of cast aluminum pulleys produced using green sand molds. Given the increasing demand for sustainable materials in industrial applications, PKS and palm seeds serve as eco-friendly alternatives to enhance casting properties. The research aims to improve aluminum pulley performance and address fatigue failure by optimizing material composition. A systematic experimental approach was adopted, incorporating varying PKS and seed percentages into the green sand mold. Three specimens (A, B, and C) were cast using silica sand, starch as a binder, fibrous PKS, and reducing agents from palm seeds. The study assessed mechanical properties such as tensile strength, hardness, elongation, and surface quality, along with dimensional accuracy, mold strength, and thermal stability. Comprehensive testing, including macro inspection, hardness tests, microscopic examination, impact tests, and machining analysis, was conducted. The results revealed that adding PKS and seeds significantly enhanced mold cohesion, thermal resistance, and overall mechanical properties of the cast aluminum pulleys. Optimal performance was achieved at a specific blend ratio, demonstrating the effectiveness of PKS and palm seeds as sustainable foundry additives. The incorporation of PKS and seed-grounded powder (PKSP) improved the thermal stability, permeability, and flowability of the green sand mold, reducing casting defects and enhancing durability. This study underscores the potential of integrating palm kernel by-products into metal casting to enhance product quality while promoting sustainability. By advancing resource recovery and waste reduction strategies, the research contributes to developing more sustainable and efficient aluminum foundry processes, aligning with circular economy principles.

Keywords*: Cast aluminum pulleys, Palm kernel shells, Palm kernel seeds, Green sand mold, Microstructure, Mechanical properties, Sustainable metal casting*

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Background to the Study
Additives in molding sand significantly influence the characteristics of cast products. This study focuses on the impact of incorporating palm kernel shells and seeds into molding sand for aluminum pulley casting, aiming to mitigate frequent failures such as fractures and bending due to fatigue. Aluminum castings, particularly in pulleys, are widely utilized in industries like automotive, machinery, and construction due to aluminum's strength and lightweight properties. A pulley is a grooved wheel designed to hold a rope or cable, functioning as a simple machine to redirect force and reduce the effort needed to lift heavy loads. By using multiple pulleys, the required force decreases, though it must act over a longer distance. While the exact origin of the pulley is unknown, early civilizations used crude rope-and-branch mechanisms to lift heavy objects, albeit with significant friction. By 1500 B.C.E., Mesopotamians were employing rope pulleys for hoisting water, and later, Archimedes developed the first documented block-and-tackle pulley system, capable of moving large warships with minimal force.

Despite its advantages, aluminum production is highly energy-intensive, contributing to substantial carbon emissions. In response, recent efforts have focused on integrating natural fibers and agricultural by-products into metal matrices to enhance mechanical performance while promoting sustainability. Palm kernel shells, a by-product of palm oil processing, and their seeds present an innovative and eco-friendly alternative for improving aluminum casting properties. Their use not only enhances product durability and performance but also aligns with global sustainability efforts.

Pulleys play a crucial role in power transmission between shafts using flat belts, V-belts, or ropes. They also assist in lifting loads and regulating rotational speeds in mechanical systems. Incorporating palm kernel shells and seeds into aluminum casting offers both economic and environmental benefits, paving the way for more sustainable manufacturing practices in the foundry industry. Pulleys are commonly made from cast iron due to their affordability. The rim is supported by a web, which connects it to the central hub through arms or spokes that may be either straight or curved. When the pulley contracts during cooling in the mold, the arms experience stress, making them prone to breaking, whereas curved arms are more flexible and less likely to fracture. Cast iron pulleys typically have round rims and are widely used due to their durability (Nashua, 2000).

Steel pulleys, made from pressed steel sheets, offer superior strength and durability. They are 40% to 60% lighter than their cast iron counterparts of the same capacity and are designed for high-speed applications. These pulleys also maintain a friction coefficient with leather belts comparable to that of cast iron pulleys. Additionally, steel pulleys often come with interchangeable bushings, allowing them to fit shafts of different sizes. Wooden pulleys, being lighter and having a higher friction coefficient than both cast iron and steel pulleys, weigh about two-thirds of an equivalent cast iron pulley. Typically crafted from selected maple, they are assembled in segments and bonded under high pressure. To prevent moisture absorption and warping, they are coated with protective layers of shellac or varnish. These pulleys are primarily used in motor drives where belt contact is limited. Paper pulleys, composed of compressed paper fibers with a metal core, are mainly used in belt transmissions from electric motors when the shaft-to-shaft distance is small. Fast and loose pulleys are often employed in mechanical systems to enable controlled power transmission. A fast pulley is fixed to the shaft to drive the machine, while a loose pulley rotates freely. The belt moves to the loose pulley when power transmission is not required, allowing the operation of multiple machines on the same shaft without interference.

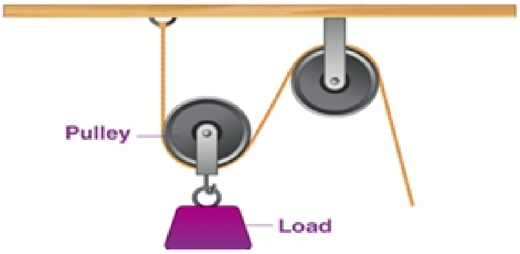
In recent years, the growing emphasis on sustainability and resource conservation has driven significant interest in developing eco-friendly materials for metal casting. The increasing industrial demand, coupled with environmental concerns, has encouraged the adoption of sustainable practices, particularly in the foundry industry. One promising area of research is the use of agricultural by-products as casting additives, offering both ecological and resource-efficient benefits. This study explores the potential of palm kernel shells and seeds as reinforcing additives in the aluminum casting process using green sand molds. As abundant biomass by-products of palm oil production, these materials provide a renewable alternative to conventional casting additives while reducing agricultural waste. Their incorporation into metal casting supports circular economy principles and aims to enhance key properties of cast aluminum, such as strength, surface finish, and durability.

By leveraging green sand molding—valued for its adaptability and cost-effectiveness—this research assesses how palm-derived additives influence the mechanical and physical properties of cast aluminum pulleys. The study evaluates factors like tensile strength, hardness, and wear resistance to determine performance improvements in the final product. The findings aim to establish the feasibility of integrating agricultural waste into casting processes, not only promoting sustainability but also reducing the environmental footprint of traditional metal casting. This research contributes to advancing sustainable foundry operations and encourages further exploration into renewable materials in industrial applications, fostering a more eco-conscious and economically viable manufacturing sector.

What is a Pulley

It is a simple wooden or metallic machine that uses a wheel and rope to lift heavy loads. Nowadays, plastic pulleys are also available in the market to carry small loads. This can be rotated freely about an axis passing through its center. It can change the direction of a force which makes it much easier for people to lift anything (Byju's, 2024). With this, you can pull down on one end to lift the 10 kgs and one-meter-high object.

Figure 1.



Source: Byju's, 2024

History of Pulley

From the time memorable mankind has built unbelievable and phenomenal structures touching remarkable heights by building multiple stories. It is not a lesser-known fact by now that even every mediocre city has a sky scraper. Not to mention that very sophisticated machinery is used to make things as possible as convenient and to make it a time-saving procedure. However, to make buildings of such a great infrastructure one requires lifting various raw materials for the construction and for such purposes structures with pulleys are required to pull. Not just limited to the construction of the building but also in various other functions where pulling is required in the industries pulleys are used in countless machines, structures and devices. (Novak, R.2024)

Types of Pulleys

A pulley is a type of simple machine. As we know, there are three types of simple machines: the pulley, the lever and the inclined plane. All three types of simple machines have been identified as such because of their simplistic nature that help accomplish work (Novak, R.2024)

Among the pulley simple machines, there are three different types of pulleys are:

i. Fixed.
ii. Moving.
iii. Compound.
iv. Block and Tackle.
v. Cone.
vi. Swivel eye.
vii. Fixed eye (The Best guide,2023)

the greatest multiplication of force. These compound systems can not only change the direction of the load, but also because of its use of compound pulleys, required less force to

Fixed Pulley

When the block of the pulley is fixed on a high platform, it is known as fixed. An extensible string passes over the groove where its one end is attached to the body to be lifted while the other end is free. Moreover, fixed pulleys are a very common pulley. These pulleys are secured to a single spot. The name fixed is because the pulley itself remains stationary, attached to something like a wall or ceiling, while the cord or rope passes through it. Because the pulley is fixed, the force that is applied on the side you are pulling will be the same amount of force that is exerted on the opposite side. So why use a fixed pulley if its capabilities are only to exert the same amount of force you, the user, applies? Well, the fixed pulley is very necessary because it's changes the direction of the object; which can be very helpful.

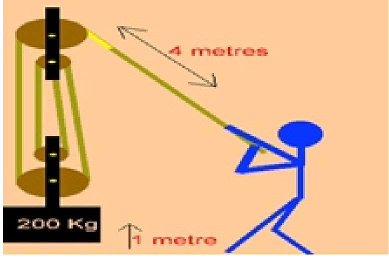
Movable Pulley

When the block of the pulley is not fixed but carries the load, it is known as Movable. An extensible string is tied around the groove where its one end is fixed to fixed support while the other end is kept free to apply the effort. As the effort is applied, they block together with the load moves upward. (The Best guide,2023)

However, Movable Pulleys are yet another type of pulley. It differs from the fixed pulley because the actual pulley machine will move with the load. Because the pulley moves with the load, moveable pulleys will multiple forces which the user applies to the machine in doing work on an object. These pulleys are often attached to the actual object, in contrast to the fixed pulley which is attached to something stationary. Unlike the fixed pulley, the movable pulley does not change the direction of the object; it is also helpful because of its multiplication of force on the opposite side of the user. This is ideal for heavier loads because you have to exert less force but that force gets multiplied.

Compound Pulley Systems are a combination of both movable and fixed pulleys. This type of pulley system has the greatest success in moving your heaviest loads. It has been exerted by the user. (Novak, R.2024)

Figure 2.

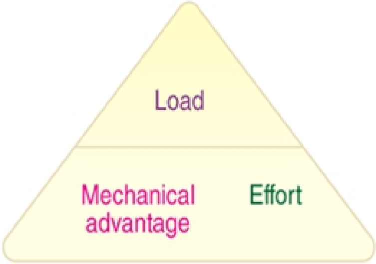


Source: Novak, 2024

Pulley Formula
Following are the formulas that are used when pulleys are used for lifting. There are formulas that are important and they are:

Mechanical Advantage Formula: It is defined as the ratio of load to the effort.

Figure 3.



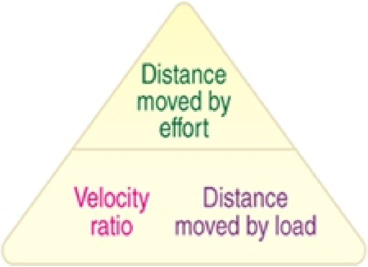
Source: Byju's, 2024

Using a single formula inside the triangle, mechanical advantage, load, and effort can be generated.

i. Mechanical advantage = (Load/Effort)
ii. Load = Mechanical advantage*Effort
iii. Effort = (Load/Mechanical advantage)

iv. Velocity ratio: It is defined as the ratio of the distance moved by the effort to the distance moved by the load.

Figure 4.



Source: Byju's, 2024

Using a single formula inside the triangle, distance moved by the load, velocity ratio, and distance moved by the load can be generated.

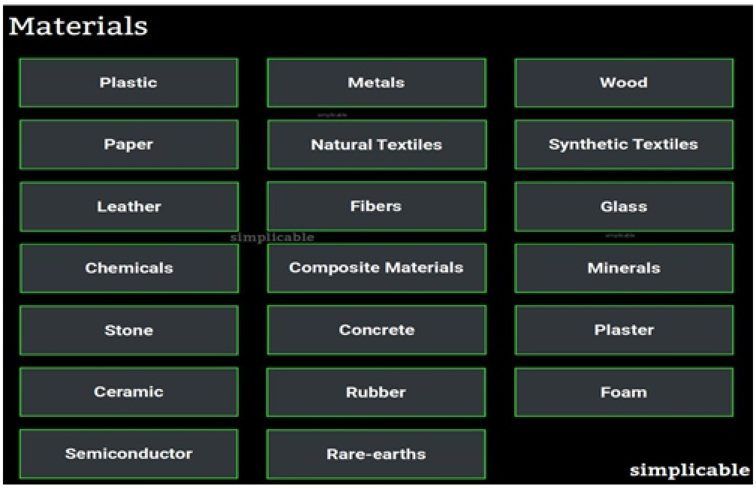
i. Distance moved by load = (distance moved by effort/Velocity ratio)
ii. Velocity ratio = (distance moved by effort/Distance moved by load)
iii. Distance moved by effort = Distance moved by the load*Velocity ratio

Materials for Engineering Manufacturing & Production

I. Biomaterials.
ii. Ceramics.
iii. Composites.
iv. Concrete & Aggregates.
v. Metals.
vi. Polymers/Plastics.
vii. Semiconductor Materials.

A material is a substance that people find useful such that it is produced for economic reasons. Materials are commonly used to produce parts, components and products. They are also used to build infrastructure, buildings and landscapes. Materials can also be consumed in processes such as farming, manufacturing and logistics. The following are common types of material (Spacey, 2023)

Figure 5.



Materials

Plastic
Metals
Wood
Paper
Natural Textiles
Synthetic Textiles
Leather
Fibers
Glass
Chemicals
Composite Materials
Minerals
Stone
Concrete
Plaster
Ceramic
Rubber
Foam
Semiconductor
Rare-earths

Source: Spacey, 2023

Metals
Metals and alloys such as iron, aluminum, titanium, copper, tin, nickel, silver, gold, steel, brass and bronze (Spacey, 2023)

Aluminum Pulley
There are various options available in the market within the pulley which lays down various options in the matter of the material used to manufacture it. The choices one can execute for pulleys are wooden, plastic and various other metals, however, it's worth mentioning that aluminium is the best possible choice.

There are various reasons to choose the aluminium pulley over other options and the major one of them are certainly mentioned below:

High Tensile Strength: One of the strongest suits of the aluminium pulleys is that they are highly strong and the best-suited metal for countering the load ought to be lifted by the same. When compared with the other metals aluminium out shine in this attribute and hence is a witty choice which will make it exceptionally durable for use. (Jaygel matal engineering works, 2022).

Corrosion-Free: Another laudable feature of the aluminium pulley is that they are corrosion resistant. This trait which helps the pulley not to decompose or deteriorate certainly maintains the quality of the pulley as it is. This significantly helps in making it more sustainable and harder to make it more suitable for the tasks in the field. (Jaygel matal engineering works, 2022).

Polished and Shiny: When polished they appear shiny and look appealing and clean. However, this smooth surface promotes the easy pulling of the loads without any hindrance and trouble. Also, it makes it appear an all-time new pulley which is an appreciable feature altogether. (Jaygel matal engineering works, 2022).

Cost-effective: One of the foremost attributes of the aluminium pulley is that they are very cost-effective. A person with advanced financial vision can easily understand that going for the aluminium pulley is the best option when compared to the advantages offered by it in the affordable range. (Jaygel metal engineering works, 2022).

High Availability: In addition to other features, it's important to count that they have high availability in the market and one can easily purchase them without much trouble. (Jaygel matal engineering works, 2022). So, it's pretty convincing from the above discussion that opting for the aluminium pulley is the best possible choice to fulfil the purpose of pulling.

Benefits of aluminium

The Benefits of Aluminium Pulleys in Industrial Work In many industrial applications is that it outperforms more traditional materials like copper and steel. Between its affordability, durability, reliability, and flexibility, aluminium does it all. (Jaygel matal engineering works, 2022).

Examples of Aluminium Pulleys

Figure 6.

Source: Rajcat, 2024

Materials

Aluminum is one of the metals to be discovered by humans, it does not occur naturally in its purest form. It is the third most abundant element comprising 8% of the earth's crust. It is also in group 13 on the periodic table. Aluminum is found in most rock, clay soil, and vegetation combined with oxygen and other elements, Aluminium was named after alum, which is called "alumen" in Latin. This name was given by Humphry Davy, an English chemist who in 1808, discovered that Aluminium could be produced by electrolytic reduction. (Amman 1999). The A356 aluminum alloy was chosen for casting due to its favorable mechanical properties, which include exceptional strength-to-weight ratio, Low density, Lightweight, High strength, Malleable, easily worked e.g. (machining), and Excellent corrosion resistance making it an ideal candidate for manufacturing durable pulleys. (Virdi, 2016).

Palm Kernel Shells and Seeds: These were sourced from local palm oil processing units, thoroughly dried, and then ground into a fine powder form. This processing facilitated a uniform mixing process thereby optimizing the bonding characteristics between the organic materials and the metal matrix. Due to the following properties:

i. Low ash content
ii. High calorific value
iii. Low sulphur content
iv. Low dust and impurities content
v. Activated carbon
vi. High oil content (Olutoge, 2014)

In this study, the palm kernel shells and seeds were incorporated into a matrix mixture at varying weight percentages of palm kernel shells and seeds powder. The mixture was preheated under controlled conditions and subsequently subjected to melting and casting processes utilizing sand molds specifically designed to ensure uniformity and quality in the final cast products.

Table 1: Sand Mixing Ratio

Materials	**Specimen A (Control) 100% (Naturally bonded sand)**	**Specimen B 100% (synthetic sand)**	**Specimen C 100% (synthetic sand)**
Silica sand	90.25 %	86.25%	84.75%
Dextrin (starch) (Binder)	4.5%	4.5%	4.5%
Palm kernel shell (fibrous material)	2.25%	4.5%	5%
Palm kernel seed (reducing agent)	2.25%	4.5%	5%
Water (negligible)	0.24%	0.24%	0.24%
TOTAL	99.99	99.99%	99.99%

The total mixture is 100kg = 100% of the total mixture

Plate 1: Casted Pulleys A, B, C

Characterization Techniques

After macro examination, other related mechanical properties were thoroughly evaluated, including Machining test, Hardness, Impact resistance and Metallographic examination, using recognized standard testing equipment's and procedures. ASTM E18 for hardness testing and ASTM D256 with serial No. 053158(for impact testing) was used, in addition to those above, a comprehensive microstructural analysis was conducted with aid of Scanning Electron Microscopy (SEM) Model No. NJF 120A to examine the dispersion, bonding quality, and overall integration of palm kernel shells and seeds within the aluminium matrix.

Test and Results

The results of the investigation analysis through the following test with respect to this research, macro-observation, microstructure, hardness, and Machining and impact test) are as follows:

Table 2: Macro Observation and Result

S/N	Observation	Specimen A (Control) (Naturally bonded sand)	Specimen B (synthetic sand)	Specimen C (synthetic sand)
1.	Texture	Very Smooth	Smooth	Rough
2.	Appearance	Very bright	Bright	Dark

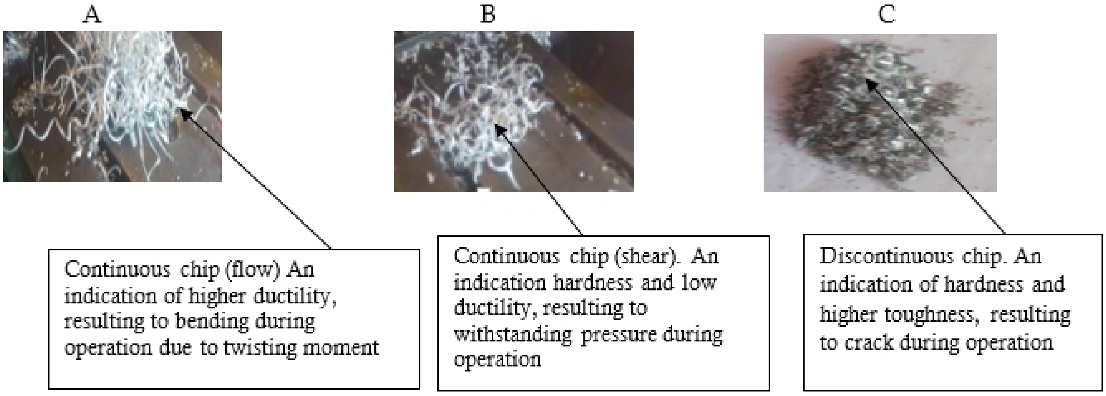
Plate 2:

Specimen A Specimen B Specimen C

Table 3: Machining Test result

S/N	Feed Rate/Speed (mm/rpm)	Specimen A (Control) (Naturally bonded sand)	Specimen B (synthetic sand)	Specimen C (synthetic sand)
1.	At speed 2mm/50rpm	Continuous chip (flow)	Continuous (shear)	Discontinuous chip

Plate 3:



Continuous chip (flow) An indication of higher ductility, resulting to bending during operation due to twisting moment

Continuous chip (shear). An indication hardness and low ductility, resulting to withstanding pressure during operation

Discontinuous chip. An indication of hardness and higher toughness, resulting to crack during operation

Impact Test, Hardness and Metallographic Test: The cylindrical block below is removed from each Specimen during the machining test for the purpose of Impact test, Hardness and Metallographic Test.

Plate 4:

A B C

Hardness Testing Procedure and results
The Machine Used: Indented universal hardness testing machine.
Model Number: 8187.5LKV model (B)
Scale: HRB (hardness Rockwell (B), the pieces of the specimens was placed on the indented universal hardness testing machine Rockwell (see plate above), with indenter size, 1/6 inch, and punches each circular block (specimens) seven time by varying the load and the average effect was recorded.

a) **Indenter used**: 1/16-inch steel ball indenter.
b) **The maximum load used**: 100kgf.
c) **Minor load used**: 10kgf.

Plate 5: Universal hardness testing machine

The table below shows the result obtained after testing exercise

Table 4: Hardness Indentation (BHN) Test deformations Rate Result

S/N	**Specimen**	**1st (HRB)**	**2nd (HRB)**	**3rd (HRB)**	**4th (HRB)**	**5th (HRB)**	**6th (HRB)**	**7st (HRB)**	**Mean (HRB)**
1	Naturally bonding sand (control) (A)	62.0	62.3	63.6	52.6	**47.4**	**40.0**	**35.6**	**51.93(HRB)**
2	Synthetic sand (B)	76.0	77.4	78.4	78.2	**73.3**	**72.8**	**66.6**	**74.67(HRB**
3	Synthetic sand (c)	76.0	77.4	78.3	78.1	**73.0**	**72.4**	**66.2**	**74.47(HRB**

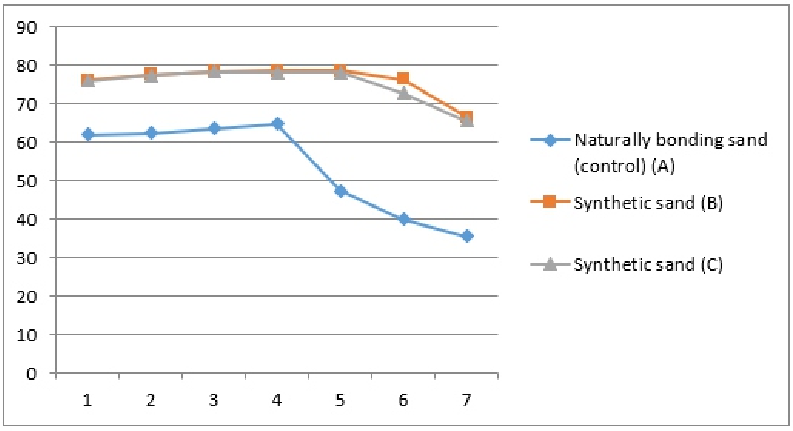
The result of the effects has been analyzed graphically using the table below

Table 5: Hardness Test Graphical Deformations Rate Result

S/N	**Specimen**	**1st (HRB)**	**2nd (HRB)**	**3rd (HRB)**	**4th (HRB)**	**5th (HRB)**	**6th (HRB)**	**7st (HRB)**	**X**
1	Naturally bonding sand (control) (A)	62.0	62.3	63.6	52.6	**47.4**	**40.0**	**35.6**	**Y1**
2	Synthetic sand (B)	76.0	77.4	78.4	78.7	**73.3**	**72.8**	**66.6**	**Y2**
3	Synthetic sand (c)	76.0	77.4	78.3	78.1	**73.0**	**72.4**	**66.2**	**Y3**

Form the graph below, it can be observed that, specimen A casted from naturally bonded sand failed instantly (bend) with respect to additional Rockwell load of 63.6 HRB while specimen B was able to moved further without crack, to78.4 HRB due effect 4.5 % of the additives giving the deference of about 14.8 HRB capacity and gradually deform (bend) with respect to additional Rockwell load. Moreover, although specimen C was able to moved further to78.4 HRB but fractures rapidly (crack) with respect to additional Rockwell load due to higher content the additives (5%)

Hardness test Graphical Deformations Rate Result



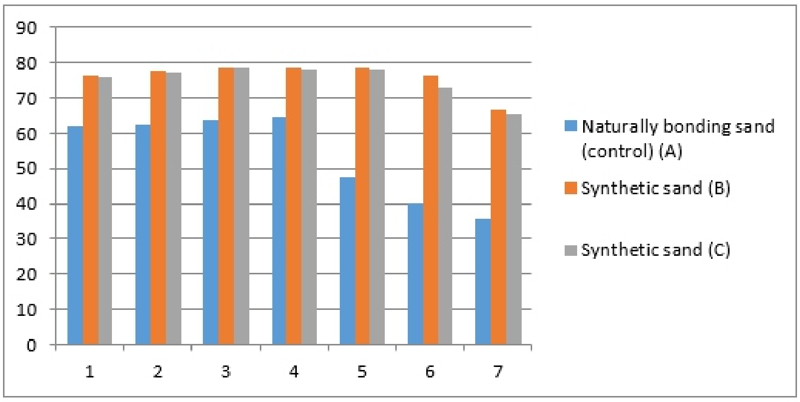


Plate 6: Table 5 hardness test bar chart deformations rate solutions

Similarly, form the bar chart above, it can be observed that, the blue bar representing specimen A casted from naturally bonded sand stop at 63.6 HRB and failed (bend) with respect to additional Rockwell load HRB. While brown color graph representing specimen B was able to moved further to78.4 HRB longer than the ash color with without failing to about 14.8 HRB and gradually deform (bend) with respect to additional Rockwell load, indicating the quality increase due effect 4.5 % of the additives.

Moreover, the ash color bar representing specimen C which failed (short than brown color) representing specimen B deform rapidly (crack) with respect to additional Rockwell load due to higher content of the additives (5%) that increases hardness and toughness of the material beyond necessary.

Impact Test and deformations rate results obtained

Machine: Chirpy Impact testing machine was used and the average effect was recorded according to the Capacity of the machine (25J) With the Serial No: 412-0.7-15269C.

Table 6: Impact Test Deformations Rate Results

S/N	Specimen	1st Reading (J)	2nd Reading (J)	3rd Reading (J)	4th Reading (J)	5th Reading (J)	6th Reading (J)	7th Reading (J)	Mean (J)
1	**Naturally bonded sand (A)**	0.40	0.60	0.80	0.60	0.56	0.52	0.45	0.56
2	**Synthetic sand (B)**	0.70	1.00	1.35	1.20	1.13	0.94	0.82	1.02
3	**Synthetic sand (C)**	0.71	1.01	1.40	1.21	1.14	0.98	0.85	1.04

However, the result of the effects has been analyzed graphically from the table below in

Table 7: Impact test deformations rate results graphical solutions

S/N	Specimen	1st Reading (J)	2nd Reading (J)	3rd Reading (J)	4th Reading (J)	5th Reading (J)	6th Reading (J)	7th Reading (J)	X
1	**Naturally bonded sand (A)**	0.40	0.60	0.80	0.60	0.56	0.52	0.45	0.56y
2	**Synthetic sand (C)**	0.70	1.00	1.35	1.20	1.13	0.94	0.82	1.02y
3	**Synthetic sand (B)**	0.71	1.01	1.40	1.21	1.14	1.45	0.85	1.08y

From the graph below, it can be observed that, the blue color graph representing specimen A casted from naturally bonded sand failed just at 0.80J impact load capacity as it elastic limit. While the Specimen B which its elastic limit was highly improved due to the effect of the new additives and represented by brown color graph, withstand the pressure and moved further to 1.45J impact load capacity before fracture. Specimen C represented by an ash color graph also moved further to 1.13J impact load capacity as its elastic limit with deference of about 0.12J below Specimen B, fractured instantly, due to higher content of the additives (5%) that increases hardness and toughness of the material beyond necessary.

Impact Test Graphical Solutions

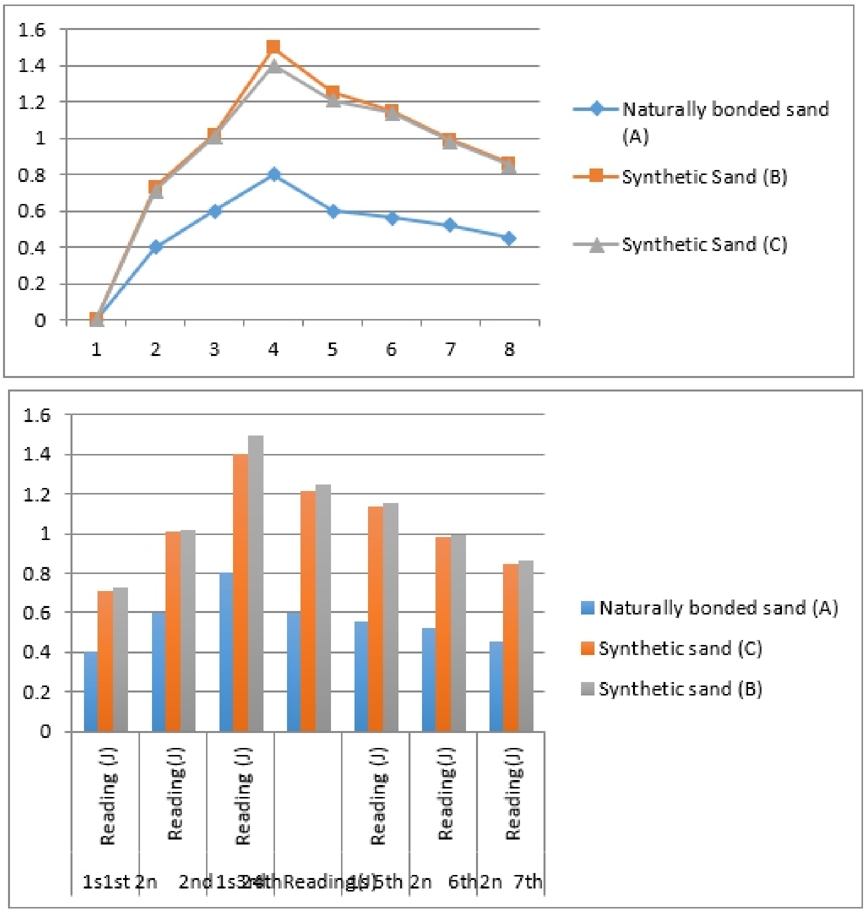


Plate 7: Impact test bar chart deformations rate solutions

Similarly, from the bar chart above, it can also be observed that, the blue color bar representing specimen A casted from naturally bonded sand failed just at 0.80J impact load capacity due to higher ductility. While Specimen B which was highly improved due to the effect of higher percentage of the new additives and represented by an ash color bar, withstand the pressure and the bar moved further to 1.45J impact load capacity due to increase in its elastic limit was highly improved as a result of the effect of the new additives which enabled it to withstand pressure and moved further without fracture. Hence Specimen C represented by brown color graph also moved further to 1.13J impact load capacity with deference of about 0.12J below Specimen B. and fractured instantly, due to higher content of the additives (5%) that increases hardness and toughness of the material beyond necessary. Hence it is unsuitable for the casting.

Crystallographic examination (Micro test) and testing procedure

Crystallographic examination test was conducted on the specimens as follows:

i. The cast components were grounded after machining process using different sizes of silicon carbide grinding paper such as 320, 400, 600, 800 and 1200. After grinding, the material was washed to remove unwanted particles before etching takes place. (Etching is the chemical application on the surface of the polished metal for better viewing using microscope).

ii. **The etching process are:** Pouring of 190ml of distilled water, 5ml of nitric acid, 5ml of hydrochloric acid, and 2ml of hydrofluoric acid. After the chemicals have been mixed properly it react and change states to Keller's reagent or solution.

iii. The material was immersed for two (2) minutes inside the Keller's solution for reaction to take place, and was later removed and dry.

After all these have been carried out successfully, Parts of these specimens was cut, polished, etched and their respective grains was examining under a computerized metrological Microscope; model number 120A with magnification rate of$^{40}x/_{0.65}$ and the following result was recorded.

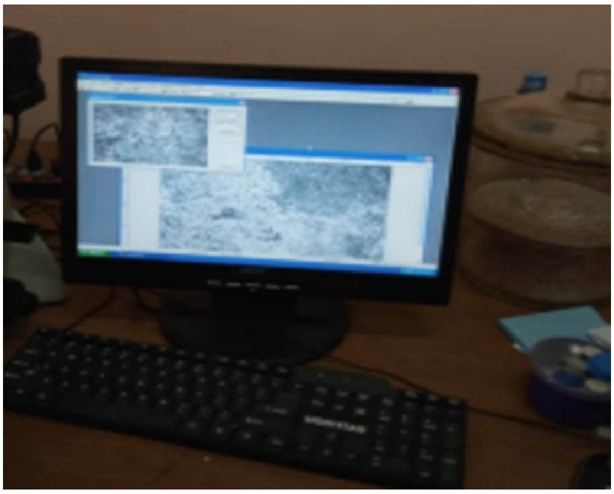
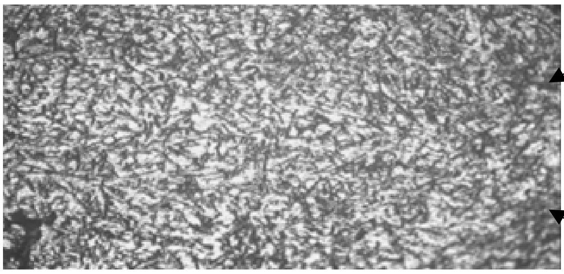


Plate 9: NJF 120A with magnification rate of $^{40}x/_{0.65}$

Metallographic examination of specimens

Specimen A results

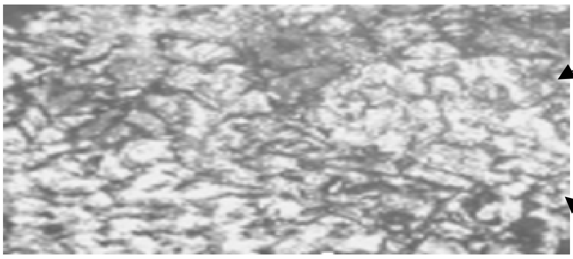


Un-uniform distributions of small dendrites aluminium phase (Small grains size) resulted to Continuous chip (flow). An indication of higher ductility, resulting to bending during operation due to twisting moment.

Distributions of small aluminum silicate phase, and smaller size of dendrites Aluminum phase in specimen **A** determines the rate of ductility of the product leading to bending deformation as a failure

Plate 10: Small Grains as a sign of higher ductility

Metallographic examination of specimen B

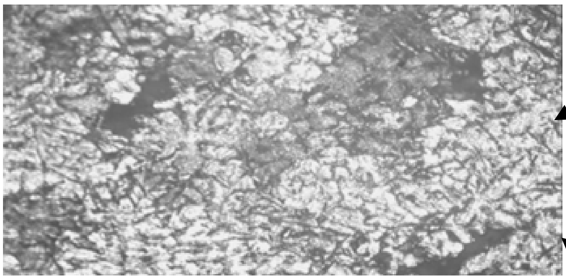


Uniform distributions of medium dendrites Aluminium phase (Uniform grains size), specimen B resulted to continuous chip (shear), as an indication of hardness and low ductility, resulting to withstanding pressure during operation. As the best product. Hence 4.5% of these additives are recommended for the production of Aluminium component (Specimen B)

Distributions of medium aluminum silicate phase, increases the qualities of the casting due effect of the new additives

Plate 11: Medium Grains size, as a sign of low ductility)

Metallographic examination of specimen



The Rate of dendrites Aluminum phase (large grains size) Specimen C. determines the rate of toughness of the product which cause it to crack due to increase in hardness of the product. Hence 5% of these additives are not recommended for the production of Aluminium component (Specimen C)

Distributions of large dendrites aluminum silicate phase. Resulted to discontinuous chip. An indication of hardness and higher toughness, resulting to crack during operation

Plate 12: Even Grains size, as a sign of ductility

Discussion of the Result

The results of the effect of the palm kernel seed and its shells on the physical, Mechanical properties and the micro graphic structures as well as the Machine ability of the cast aluminum pulley examined, are presented in plates 1 - 12 and Tables 1 - 7 which includes the graphs and bar chart detailed respectively. The effects of the seeds oil moisture contents (5%) as the reducing agent and graphite activation absorbed during the casting process by the metallic grains from the shells as the fibrous material, indicate the reasonable effects on the characteristics values of the aluminum pulley examined as shown in the plates and Tables presented above respectively. The differences observed from the macro examination; the Texture result of the specimen A was very smooth while for the specimen B it looks smooth. While spacemen C is Rough. The Appearance of specimen A was very bright. However, for the specimen B, it looks bright, while specimen C is dark due to higher content of the additives (5%).

Moreover, the machining test indicates that, specimen A gave continuous chip (flow) an indication of higher ductility, resulting to bending during operation due to twisting moment. While specimen B produced continuous chip (shear). As an indication of hardness and low ductility, resulting to withstanding pressure during operation without fractures. Specimen C generates discontinuous chip. An indication of hardness and higher toughness, resulting to crack during operation. Crystallographic examination test was conducted on the specimens A, B and C. The sizes and shape of the dendrites Aluminum phases (grains sizes) and distributions of small aluminum silicate phase of dendrites Aluminum phase in specimen A proved the rate of ductility of the product, leading to bending or twisting deformation as a failure due to fatigues or stress. Similarly, the uniform distributions of medium dendrites Aluminium phase (Uniform grains size), and distributions of medium aluminum silicate phase, increases the qualities of the casting due effect of the new additives in specimen B during examination, these resulted to continuous chips (shear), as an indication of hardness and low ductility, proving the withstanding of pressure during operation. As the best product. Hence 4.5% of these additives are recommended for the production of Aluminium Pulleys. (Specimen B) Moreover. The rough image of the dendrites Aluminum phase (large grains sizes) and distributions of large dendrites aluminum silicate phase. Resulted to discontinuous chips in specimen C these indicates the rate of toughness of the product which resulted to increase in hardness of the product that make it crack due to stress during operation. Hence 5% of these additives are not recommended for the production of Aluminium component (Specimen C).

The Hardness was conducted on the Indented Universal Hardness testing Rockwell Machine, with following indent size, 1/6-inch (steel ball) and punched each specimen for about seven (7) times and the average effect indicated that, specimens A start failing right from 63.6 load capacity (HRB) due to additional Rockwell load on the hardness Rockwell load. The graphical result which was very low if compared with Specimens B produced from a synthetic sand that contained palm kernel seed and its shells, was able to moved further without crack, to78.4 HRB due effect 4.5 % of the additives giving the deference of about 14.8 HRB capacity and gradually deform (bend) with respect to additional Rockwell load capacity (HRB) on the hardness Rockwell load, with difference of 14.9 load capacity (HRB). Moreover, although specimen C was able to moved further to78.4 HRB but fractures instantly (crack) with respect to additional Rockwell load due to higher content the additives (5%).

Impact Test examination was also conducted and Chirpy Impact testing machine was used and the average effects was recorded in which the result show that, the Specimen B produced from Synthetic sand containing 4.5 % of palm kernel seed and its shells powder respectively was record, and the impact load capacity of 1.45J on the bar chart result indicates higher level of strengthens than the specimen A that was produced using naturally bonded sand that gives record of 0.80J impact load capacity and specimen C that fractured instantly beyond 1.13J, due to higher content of the additives (5%) that increases hardness and toughness of the material beyond necessary. Therefore, it was summarized that, Synthetic sand containing palm kernel seed and its shells powder 4.5% as additives (specimen B), is the best sand to be used for aluminum casting from the stated results above. This is because the dendrite grains phase and aluminum silicate phase of specimen B are uniformly distributed which led to indication of good result in all the test and examinations.

Mechanical Properties

The systematic application of palm kernel shells and seeds as part of the mixture introduced and exhibited a significant effect on the mechanical properties of aluminum cast pulleys. This is because the hardness and tensile Strength increased significantly as the percentage of palm kernel shells and seeds increased, achieving optimal enhancement at 85% reinforcement level due to a change in the dendrite and silicate phase of the Aluminium. However, beyond this percentage, a decline in tensile performance was observed, indicating a potential threshold for effective reinforcement.

Hardness: The hardness measurements revealed a consistent increase with the incremental percentages of PKS and seeds, highlighting an improvement in wear resistance and an essential characteristic for enhancing the durability and longevity of pulley applications as the impact of the mixture.

Impact Resistance: Composition containing 4.5% and palm kernel shells exhibited enhanced impact resistance compared to pure Natural Sand mixture, showcasing improvement in toughness, which is vital for applications where resilience against sudden impacts is necessary.

Micro-structural Analysis

The SEM images collected during the micro-structural analysis displayed a uniform distribution of the Silicon slick phase and dendrite Aluminium phase within the aluminum matrix at minimum concentrations. However, at higher reinforcement percentages, agglomeration was noted, leading to the formation of weak points that negatively influenced the fracture as an overall mechanical property in Specimen C. It was determined that achieving an optimal particle size and distribution of the additives is critical for realizing the pulley's maximum potential performance.

Environmental Impact

Beyond mechanical enhancements, it was discovered that, the utilization of palm kernel shells and seeds by the foundry industry will significantly reduce environmental pollution and implications due to waste minimization of palm kernel shells and seeds as an agricultural waste. This innovative approach not only improves the mechanical performance of aluminum cast pulleys, but also makes a substantial contribution towards waste minimization, offering a paradigm of sustainable alternatives to conventional aluminum casting practices. By incorporating agricultural waste into industrial products, we can significantly reduce environmental footprints, foster the essence of circular economy practices, and promote resource efficiency.

Conclusion

The comprehensive study effectively demonstrates that palm kernel shells and seeds can be integrated into aluminum cast pulleys successfully, leading to substantial enhancements in mechanical properties, while simultaneously promoting principles of environmental sustainability. The optimal level of reinforcement was discovered to be 4.5% PKS and seeds par a mixture of 100kg, which achieved an impressive balance between mechanical enhancement and material integrity without compromising quality.

Recommendation

Future research endeavors are warranted to explore the long-term performance metrics and potential applications of this kind of mixture in various aluminum products, contributing to the broader agenda of sustainable material innovation.

References

Adeleke, V. A. (2015). Effects of addition of iron (Fe) filings to green molding sand on the microstructure of Grey cast iron, J*ournal of the Brazilian Society of Mechanical Sciences and Engineering*, XXXII (2)/175

Ammen, C. W. (1999). *Metal casting*, MC Graw-Hill Professional PP.159-176

Ameen, H. Z. & Hassan, K. S. (2016). Effect of the sand mould additives on some mechanical properties of carbon steel CK45 casts, *Journal of engineering*, 17, 729-739.

Anya, U. A., Chioma, N. C. & Obinna, O. (2016). Optimized reduction of free fatty acid content on neem seed oil, for biodiesel production, *Journal of Basic and Applied Chemistry, 2(*4), 21-28.

Aondona, P. I. & Aniekan, O. (2015). The study of green compression strength of a green sand mould using statistical approach, *Materials Sciences and Applications 5,* 876-882 Published Online October 2015 in SciRes.

Aydın, C. & Özcan, M. (2015). Some physico-mechanic properties of terebinth (Pistaciaterebinthus L.) fruits, *Journal of Food Engineering, 53*(1), 97-101.

Bawa, H. S. (2004). *Manufacturing processes Tata*, MC Graw-Hill. PP1-12

Chapman, W. A. J. (2017). *Workshop technology, part 1, 5th edition,* Published by Edward Arnold.

Danieli, R. (2015). *The history of aluminum cast. reliable innovative partners for the Aluminum industry,* https// www.kokomotribune.com retrieved on 23rd October, 2019 from www.google.com (9: 35 pm)

Deepak, C. (2018). Green sand management—Role & application of carbonaceous additives and concept of Total carbon in a green sand system, 68*th World Foundry Congress*, India, 127-132.

Enbangsi, K. A. (2017). *Metal casting techniques - Vacuum ("V") process molding, (retrieved 2019-11-19)*

Fetcher, F. A. J. (2015). *Workshop technology, Part 3, 4th edition,* Published Edward Arnold.

Ganguly, S. K. (2015). *International Journal of Recent Development in Engineering and Technology*, ISSN 2347 - 6435 (Online) 2(4)

History of aluminum Wikipedia https// www.aluminum, Org>castings retrieved on 23rd October, 2019 from www.google.com (9: 45 pm)

History of aluminum Wikipedia (*https//www.aluminum.org>history)* retrieved on 23rd September, 2019 from www.google.com (9: 35 pm)

http://www.themetalcasting.com/commercial-foundry.html Sand Casting retrieved on 3rd October, 2019 from www.google.com (9: 40 pm)

Ihom, A. P. (2016). *Foundry raw materials for sand casting and testing procedures*, A2P2 Transcendent Publishers, *Jos, 71-92.*

Jaygel Matal Engineering Works, (2022*). Aluminium pulley › why the Aluminium pulley has upper hand over others*, https://www.jaygelmataengineeringworks.co.in/blog/why-the-aluminium-pulley-has-upper-hand-over-others_13186.htm

Mbangsi, A. K. (2016). *A study on foundry sand: opportunities for sustainable and economical concrete, (Volume:2/issue: Jan2013.issN N0. 2277- 8160) retrieved 2020 – 06 – 5- 1:25*

Merriam, W. (nd) *Definition of moulding, Merriam-webster.com*, retrieved 04/07/2021

Mick, S. (1993). *Wheels, pulleys*, levers New York: Gloucester.

Mordue, J. A. & Alasdair, J. N. (2000). Azadirachtin from the neem tree (*Azadirachtaindica*) it's action against Insects. *Annals of the Society for Entomology,* Brasil, 29(4), 615-632.

Myers, R. H., Montgomery, D. C. & Anderson-Cook C. M. (*2009). Response surface methodology*, John Wiley & Sons, Inc., *New Jersey,*

Nanjundaswamy, O. (2017). *International Journal of Latest Trends in Engineering and Technology (IJLTET*

Nashua, N. H. (2000). *Levers and pulley*, Delta Education

Novak, R. (2023). *Henssgen hardware,* https://henssgenhardware.com/product-category/pulleys/

Olutoge, W. (2014). *Investigation of the strength properties of Palm Kernel shell Ash*, Oaji.net particles retrieved 20/11/2022

Orhevba, B. A., Idah, P. A., Adebayo, S. E. & Nwankwo, C C. (2013). Determination of some engineering properties of dika nut (*Irvingiagabonensis*) at two moisture content levels as relevant to its processing, *International Journal of Engineering Research and Applications (IJERA), 3*(2), 182-188

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R. & Simons, A. (2009). *Agroforestry database: A tree reference and selection guide version 4.0,* (http://www.worldagroforestry.org/af/treedb/), accessed 20th October, 2014.

Paul, A. (2019). Effects of the moisture content on the foundry properties of Yola natural sand, *Leonardo Electronic Journal of Practices and Technologies*, **19**, 85-96.

Recharge, W. & Heine, R. (2016). *Principles of metal casting,* Tata McGraw-Hill 2nd Editionp76

Tataram. K. Chavan, H. M., & Nanjundaswamy, H. (2016). *IJREAT:* Effect of variation of different additives on green sand mold properties for Olivine sand, *International Journal of Research in Engineering & Advanced Technology*, 1(4), ISSN: 2320 – 8791*)*

Vannoccio, B.*(2019). Published around 1540 (Additive Manufacturing), retrieved -11-14.*

Virdi, S. (2016). *Construction science and materials, 2nd edition,* www.mysearch.com retrieved 10/07/2023

Wikipedia, *The free encyclopaediaoct 17th 2016*, (retrieved 2nd /5/2020)

Wikipedia, *The free encyclopedia Dec 13, 2018*, (retrieved 6th/9/2019)